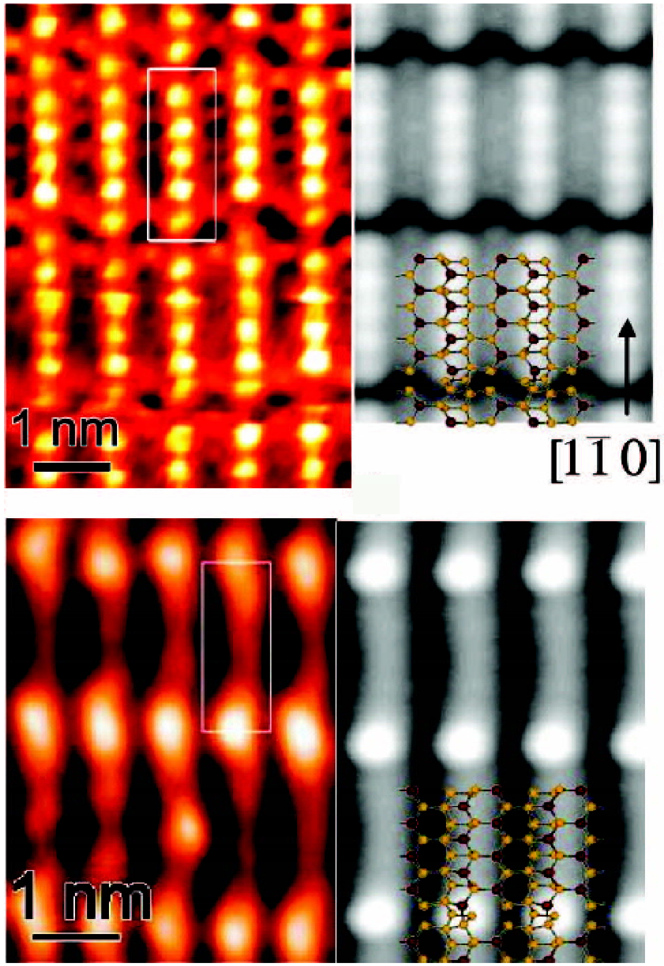
Electrical Transport in Thin Film Nanostructures
Hanno H. Weitering, The University of Tennessee, DMR 0244570

Atom wires represent the smallest electrical interconnect imaginable. Although many researchers have succeeded in making atom wires, it is not clear if and how they conduct electricity.

Atom wire arrays usually exhibit some sort of fluctuating disorder that likely impedes electrical transport. We have identified the atomic-scale nature of fluctuating defects in gallium atom wires on silicon, and provided in-depth understanding as to why such defects form. This understanding is an important step forward in devising nanowire arrays without spurious scattering centers.



C. González et al., *Physical Review Letters* (2004), in press

Deposition of small amounts of metal atoms on a crystal surface that is intentionally miscut, often results in the formation of “atom wires” or arrays of atom wires. Miscut surfaces still have leveled terraces but the terrace levels are separated by a single-atom-height step (analogous to a rice paddy). The basic idea behind atom wire formation is that incoming metal atoms preferentially adsorb at the step and thereby align themselves into single-atom-wide wires. Such atom wires are of great interest. From a technological point of view, they could represent the smallest possible conductor or interconnect. From a scientific point of view, electrons in atom wires supposedly no longer behave as single entities. In one-dimension, one can only speak about the collective of electrons, an exotic many-body state that is often referred to as the “Luttinger Liquid” state. Researchers are trying to learn more about this Luttinger liquid, which still is mostly a theoretical construct whose existence has yet to be verified experimentally.

We have focused on another property of atoms wires that is likely to be essential to their current carrying capability, namely structural fluctuations. All atomic wire systems that have been explored to date exhibit some sort of spatially fluctuating disorder. This disorder is intrinsic, meaning that it is impossible get rid off even if the fabrication procedure were 100% perfect. For the gallium wires studied here, we find that single gallium atoms are occasionally missing, thus producing “broken” wires. Neighboring atoms try to repair the “damage” by forming a new bond or “wire link”, this time involving a silicon atom. However, unlike a perfect wire, the silicon-gallium wire link is not symmetric with respect to a 180 degree rotation. These symmetry-breaking wire links produce a fluctuating defect pattern. As a result, the atom wire array is no longer strictly periodic but has become *quasi-periodic*. Structural fluctuations in one-dimensional systems are believed to be detrimental to the electrical conductivity of the wires.

The colored panels show some pictures of the gallium wires, recorded with a Scanning Tunneling Microscope. The two images are different because they were acquired under different tunneling polarities. The gray scale images are theoretical images. Even the smallest details are reproduced by the theoretical calculation which shows that we have fully pinned down the atomic-scale structure of the wires, including that of the wire links. The calculations also explain why mother nature prefers forming atom chains with symmetry-breaking wire links.

These results have been presented in the article entitled “*Formation of atom wires on vicinal silicon*” by C. Gonzalez et al. and has been accepted for publication in Physical Review Letters (2004).

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Education:

This work is the result of a collaboration with the theory group of Prof. Fernando Flores at the “Universidad Autonoma” in Madrid, Spain. It is part of the Ph.D. thesis projects of Mr. Paul Snijders and Mr. Cesar Gonzalez (Madrid). Both students are expected to graduate in 2005. Mr. Snijders is currently performing experiments on similar systems, together with Dr. Jiandong Guo, a postdoc in the PIs group. The students and postdocs in this group are exposed to a wide variety of experimental techniques and theoretical methods. Most experiments are done using state-of-the-art scientific instrumentation at UTK and ORNL, while new experiments are being devised that utilize the low-frequency radiation beam lines at Brookhaven National Laboratory (infrared) and Jefferson Laboratory (THz).

Societal Impact:

Nanoscience represents one of the most promising avenues for technological innovation. Such innovations include the realization of an ultimate downscaled quantum electronic device. Atom wires are the smallest electrical interconnect that one can possibly imagine. Fundamental understanding of the structure, stability, and electrical conductivity of these ultimate wires will provide the underpinnings that are necessary for breakthroughs and innovations in nanoscale science and technology.